

PROLIFERATION RESISTANCE CONSIDERATIONS FOR ADVANCED NUCLEAR ENERGY SYSTEMS

*Enabling Energy Security through the
Nuclear Fuel Cycle*

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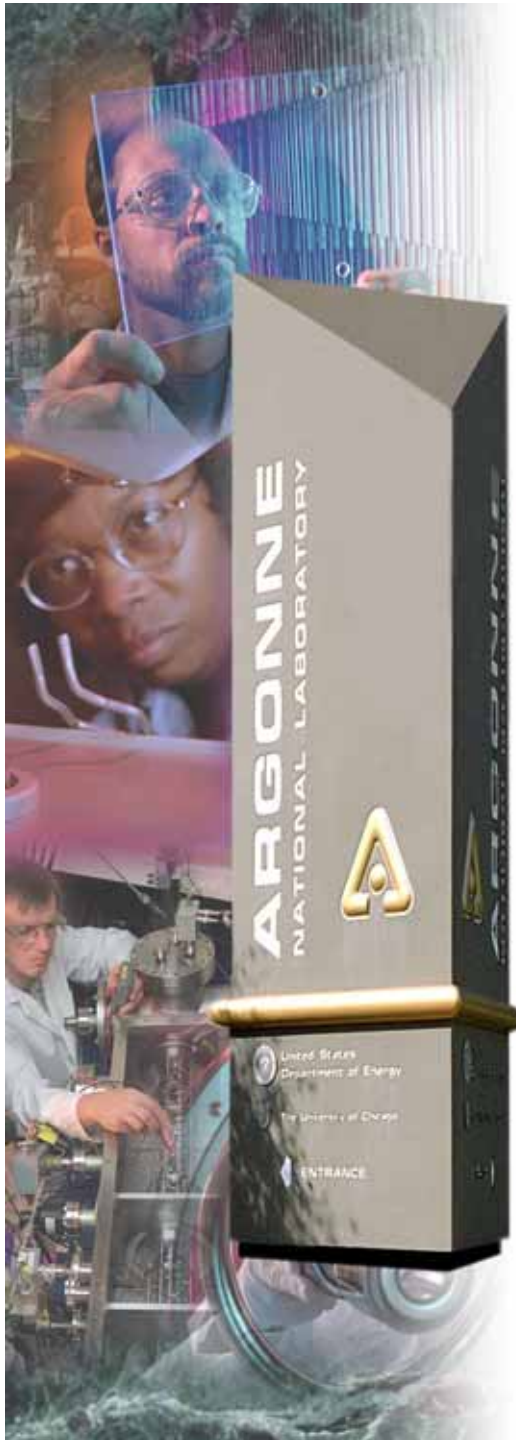
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Proliferation Resistance

- **The potential contribution of civilian nuclear systems to illicit uses of nuclear material has long been a concern**
 - Non-Proliferation Treaty; Additional Protocol
 - Nuclear Suppliers Group
 - Recent Initiatives for Nuclear Energy expansion
 - *IAEA (El-Baradei) and US (Bush) proposals*
- **Advanced nuclear energy systems are envisioned for widespread deployment during this century**
 - Includes power plant and its fuel cycle
 - Potential widespread deployment (?) of fuel cycle facilities

Generation IV Systems

Generation IV Technology Goal:

Generation IV nuclear energy systems will increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.

Proliferation Resistance in Advanced Systems

- **Advanced Nuclear Energy Systems must have robust proliferation resistance characteristics that make them the least desirable route to nuclear proliferation**
- **Assessing advanced systems for their potential to meet the Generation IV Goal requires a definition of proliferation resistance and a methodology to evaluate it**

PR&PP Expert Group

A Proliferation Resistance and Physical Protection (PR&PP) Expert Group has been organized by US DOE NE and NNSA, with participation of GIF countries and International Organizations

Purpose – Develop and demonstrate a methodology for the systematic evaluation of Generation IV nuclear energy systems with respect to Proliferation Resistance and Physical Protection (Generation IV Technology Goal)

Main responsibilities

- **Determine measures for expressing proliferation resistance**
- **Determine measures for expressing physical protection**
- **Develop a comprehensive evaluation approach**

Methodology Development Scope

Scope based on two related end objectives identified in the Generation IV Roadmap

- Proliferation resistance
 - *diversion of nuclear material from declared flows or inventories*
 - *undeclared production*
 - *replication of facilities/equipment*
- Physical protection
 - *theft of nuclear material for nuclear explosive devices or radiation dispersal devices*
 - *facility sabotage*
 - *transport sabotage*

Gen IV Methodology Approach

- **Systems are to be evaluated at different stages in their development for their potential to meet the technology goals.**
 - This offers the opportunity to integrate PR&PP in the system design
- **Systems will be evaluated for sustainability, safety, economics and PR&PP**
 - PR&PP assessment methodology can be a tool to support it
- **To the extent possible, a quantitative and standardized methodology is targeted**
 - Include the ability to identify system features that contribute to the overall system PR&PP

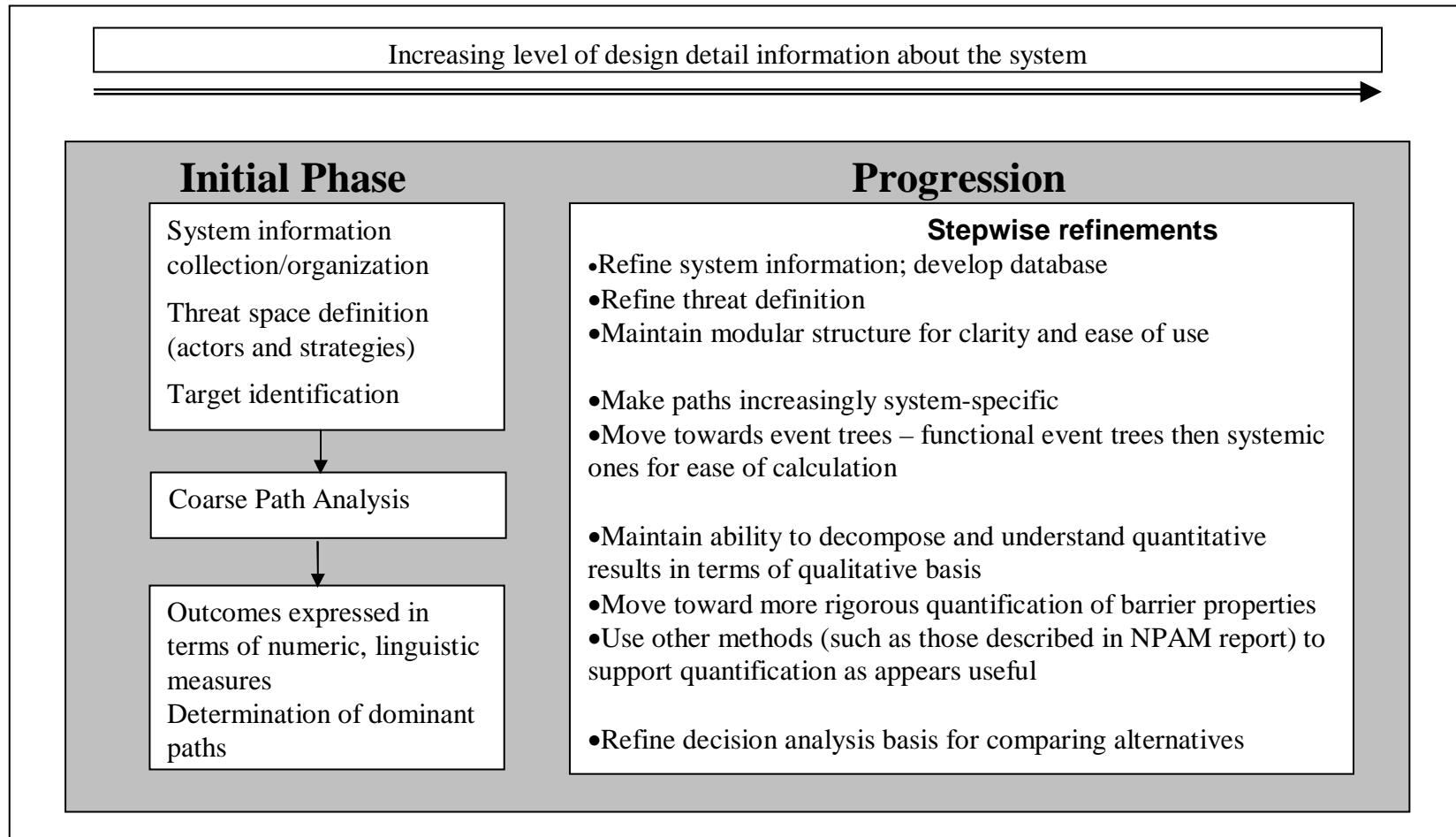
Methodology Development

- **Methodology Development Tasks**
 - Establish the overall framework for the assessment
 - Define the threat space for PR and for PP
 - Identify PR&PP measures and metrics
 - Develop a methodology to assess/quantify the metrics

Definitions and Functional Requirements

- **Proliferation Resistance (PR)**
 - That characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by States in order to acquire nuclear weapons or other nuclear explosive devices
- **Physical Protection (PP) robustness**
 - That characteristic of a nuclear energy system that impedes the theft of materials suitable for nuclear explosives or radiation dispersal devices, and the sabotage of facilities and transportation, by sub-national entities and other non-host state adversaries.
- **Functional requirements cover:**
 - Users and uses
 - Application, capabilities
 - Representation of results

Progressive Approach



Evaluation Framework



Framework is analogous to current approaches to safety analyses and vulnerability assessments

Threat Definition

- **Proliferation resistance**

- Nuclear weapons aspirations (e.g. number and characteristics of explosives)
- Proliferator strategy (e.g. diversion or undeclared production with declared facility, abrogation, clandestine production)
- Proliferator capabilities

- **Physical protection**

- Adversary strategies (e.g. theft of materials, radiological sabotage, operations disruption)
- Class of adversary (e.g. outsiders, insiders, outsiders + insiders)
- Adversary capabilities
- Adversary tactics (e.g. stealth, force, deceit)

System Response – Pathway Analysis

- **Pathways:** potential sequences of events used by the proliferator or adversary to achieve its objectives (proliferation, theft or sabotage).
- Along any pathway the proliferator or adversary will encounter various deterrents, all of which are collectively called *“proliferation resistance”* or *“physical protection robustness”*

Evaluation: Measures and Metrics

- **Measure: a major system characteristic that would be an important impediment to the strategy of a proliferant nation (PR), or of a non-state group attempting theft or sabotage (PP).**
 - Example: proliferation time
 - ***the time required to overcome the multiple barriers provided by the system to successful proliferation***
- **Highest interest is in utilization of intrinsic system features that can contribute to the PR measures.**
- **System designers can incorporate PR at the early stages of the development by enhancing intrinsic features to maximize impact on PR measures.**
 - Iterative process with other design goals

Preliminary PR&PP Measures

- **Proliferation Resistance**
 - ***Proliferation Technical Difficulty***
 - ***Proliferation Resources***
 - ***Proliferation Time***
 - ***Fissile Material Quality***
 - ***Detectability***
 - ***Detection Resources***

Preliminary PR&PP Measures (cont'd)

- **Physical Protection**
 - ***Operational Accessibility***
 - ***Adversary Delay***
 - ***Consequences and Mitigation Potential***
 - ***Detection Time***
 - ***Interruption Delay***
 - ***Physical Protection Resources***

Summary of Methodology Development

- **PR&PP evaluation method is in development**
- **Draft definitions of PR & PP measures**
- **Framework for evaluation defined**
- **Draft threat space defined**
- **Focus on user needs: provide feedback to designers and options for policy makers**
- **Development case now underway**
 - Interaction with system developers
 - Evaluation just initiated will assess the usefulness of the current PR&PP measures (Report to DOE and NNSA: 9/2004)

Methodology Development: Conclusions

The successful completion of this systematic evaluation methodology can provide a valuable tool for system developers

- Selection of design choices for enhanced PR&PP
- Integration of safeguards in design

Proliferation Resistant Fuel Cycle Technologies

- **Advanced fuel cycle technologies present new challenges to the standard safeguards**
- **Wider deployment of nuclear systems will also require an increase in safeguards efforts**

Proliferation Resistant Fuel Cycle Development

- **Joint project between DOE/NA and DOE/NE on proliferation resistance of advanced fuel cycles.**
- **Work performed jointly by Argonne National Laboratory (ANL) and Los Alamos National Laboratory (LANL).**
- **Schedule is divided into two phases.**
 - Phase 1 – Advanced design approach for an advanced fuel cycle facility integrating safeguards.
 - Phase 2 – Testing and demonstration of advanced safeguards technologies.
- **Phase 1 for an advanced facility based on pyroprocessing technology was completed last year.**
- **Currently performing Phase 1 for an aqueous facility using UREX+ technology.**

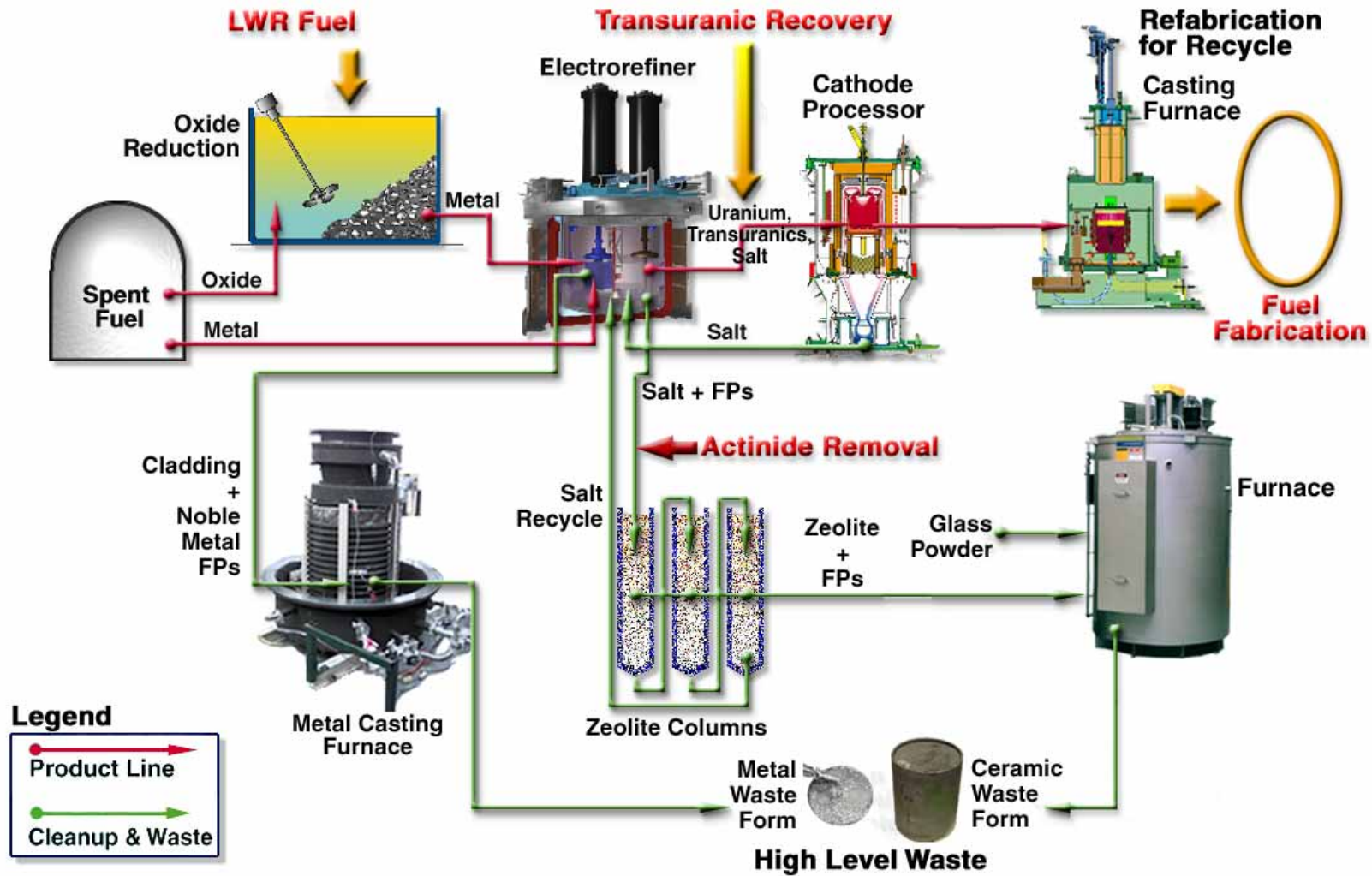
Project Objectives

- **The project goal is to develop a demonstrably effective safeguards system for advanced fuel processing technologies.**
 - Use of an integrated design approach that addresses safeguards issues directly during the design stage.
 - Assessment of the effect of this approach on the safeguardability of the facility.
 - Development and demonstration of advanced safeguards technologies.

Pyroprocessing Project – Phase 1

- **Define Generic Pyroprocess Fuel Cycle**
 - Define baseline facility layout and process definition
 - Define all flow streams and compositions
- **Develop Safeguards Approaches Including Instrumentation and Monitoring Equipment Options**
 - Establish expected safeguards requirements for baseline facility
 - Define potential advanced safeguards approaches for baseline facility
- **Evaluate, Develop, and Integrate Process, Facility, and Safeguards Instrumentation**
 - Assess safeguards approaches and impact of safeguards on facility design and operations
 - Update facility design for integrated safeguards
 - Identify technology needs and demonstration to support safeguards approach

Reference Facility



Safeguards - Generic Bulk-Processing Issues

- **Capacity**
 - Large throughput places a heavy burden on measurement uncertainties.
 - Reference facility will have 2.4 MT TRU/yr. (Rokkasho-mura ~6.4 MT Pu/yr). 1% sigma → 24 kg/yr or 2 kg/mo.
 - Can lead to limitations, e.g., on detecting one-year protracted diversion.
 - *3.3 sigma (95% detection probability with 5% false positive) is 79.2 kg/yr which is much greater than 8 kg (IAEA limit) .*
- **Initial Pu accountancy**
 - Largest source of uncertainty in PUREX plants
- **Heterogeneity**
 - NDA challenged by large batch sizes

Safeguards Approaches

- **Iterative process between safeguards approach and impact on facility design and operations**
- **Four safeguards options have been identified for further study.**
 - Neutron Balance-Cm Accounting.
 - Electrorefiner Assay.
 - Homogenized Input.
 - Assay of Pu in Spent Fuel via Pu/Cm ratio and Destructive Analysis.

Example: Electrefiner Assay Option

- **Derive Pu content via synchronized “multi-batch” measurements**
 - Assay the Pu content of all U cathodes removed from the ER using a Cm ratio technique similar to that used at the Tokai Reprocessing Plant or DA of U product after processing each day
 - Assay the Pu content of all metal waste baskets removed from the ER during a day using a Cm ratio technique
 - Assay the Pu content and the Pu/Cm ratio in the electrefiner salt prior to daily salt removal using a DA sample (assuming a homogeneous mixture can be obtained)
 - Weigh the $\frac{1}{4}$ of the ER salt removed daily and determine Pu content based on the DA sample composition
- **Assay the Pu content of the recharge salt and the recovered salts from the metal waste and U product processing units using a Cm ratio technique**

Technology Development Needs

- **Pin scan plus destructive analysis (DA)**
- **Homogenization options plus DA**
- **In-situ assay of Pu in the electrorefiner (ER) plus DA**
- **Process monitoring options**
- **Integrated video and radiation monitoring for transfer paths and penetrations**
- **Waste form measurements**
- **Near real-time accountability (NRTA) techniques**
- **Alternative chemical analyses: laser methods**

Example – In-situ ER Assay Development

- **Scope of activities**
 - Sample electrorefiner salt to demonstrate homogeneity and determine Cm/Pu ratio
 - Review of salt level measurement system for DA option
 - Determine and install optimal number of fission chambers
 - Test and calibrate equipment
 - Perform ER Assay measurements
 - DA analysis of samples
 - Measurement uncertainty
 - Examine spoofing possibilities (e.g., ^{252}Cf source)

Status of Proliferation Resistant Fuel Cycle Technologies Development

- **Phase 1 has been completed for pyroprocessing and is ongoing for UREX+**
 - Technologies to support the safeguards approaches have been identified for development and demonstration.
- **Development and demonstration of the advanced safeguards technologies in Phase 2 (proposed) will enable the determination of preferred safeguards approaches for advanced fuel cycle facilities.**

Summary

- **Proliferation Resistance will be an important element of the design and deployment of advanced nuclear energy systems**
 - Necessary for widespread deployment of nuclear power
- **A combination of intrinsic system characteristics and external actions will be necessary to ensure the desirable degree of proliferation resistance**

Summary (cont'd)

- **An evaluation methodology is in development to permit the assessment of systems and system design options for proliferation resistance.**
 - The methodology aims at providing feedback to system developers that can be used during design to enhance PR through intrinsic characteristics
- **Advanced safeguards approaches are being developed to enhance the application of external controls to advanced nuclear fuel cycle technologies**